# Chapter Twenty-nine

# HORIZONTAL ALIGNMENT

BUREAU OF LOCAL ROADS AND STREETS MANUAL

# Chapter Twenty-nine
# HORIZONTAL ALIGNMENT

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# Chapter Twenty-nine
# HORIZONTAL ALIGNMENT

Chapter 29 presents BLRS criteria for the design of horizontal alignment elements. This includes horizontal curvature and superelevation for both rural and urban local facilities.

## 29-1 DEFINITIONS

This Section presents definitions for the basic elements of horizontal alignment:

1. Axis of Rotation. The line about which the pavement is revolved to superelevate the roadway. This line will maintain the normal roadway profile throughout the curve.

2. Broken-Back Curves. Closely spaced horizontal curves with deflection angles in the same direction with an intervening, short tangent section (less than 1500 ft (500 m)).

3. Compound Curves. A series of two or more simple curves with deflections in the same direction immediately adjacent to each other.

4. Deflection Angle ($\Delta$). The external angle between the two projected tangents (beyond the point of intersection) of a simple curve.

5. Low-Speed Urban Streets. All streets within urbanized or small urban areas with a design speed of 45 mph (70 km/h) or less.

6. Maximum Superelevation ($e_{max}$). The upper limit for the superelevation rate used in the design of horizontal curves. Its selection depends on several factors including climatic conditions, terrain conditions, type of area (e.g., rural or urban), pavement type, and functional classification.

7. Normal Crown (NC). The typical cross section on a tangent section of roadway (i.e., no superelevation).

8. Open Roadway Conditions. Rural facilities for all design speeds and urban facilities with a design speed $\geq$ 50 mph (80 km/h).

9. Relative Longitudinal Gradient. For superelevation transition sections on two-lane facilities, the difference in grade between the centerline profile grade and the grade of the edge of traveled way.

10. Remove Adverse Crown (RC). A superelevated roadway section that is sloped across the entire traveled way in the same direction and at a rate equal to the cross slope on the tangent section (typically, 1.5% or 2.0%).

11. Reverse Curves. Two simple curves with deflections in opposite directions that are joined by a relatively short tangent distance or which have no intervening tangent (i.e., the PT and PC are coincident).

12. Simple Curves. Continuous arcs of constant radius that achieve the necessary roadway deflection without an entering or exiting transition.

13. Superelevation (e). The amount of cross slope or “bank” provided on a horizontal curve to counterbalance, in combination with the side friction, the centrifugal force of a vehicle traversing the curve.

14. Superelevation Rollover. The algebraic difference (A) between the superelevated travel lane slope and shoulder slope on the high side of a horizontal curve.

15. Superelevation Transition Length. The distance transitioning the roadway from a normal crown section to the design superelevation rate. Superelevation transition length is the sum of the tangent runout (TR) and superelevation runoff (L) distances:

    - Tangent Runout (TR). Tangent runout is the distance needed to change from a normal crown section to a point where the adverse cross slope of the outside lane is removed (i.e., the outside lane is level).
    - Superelevation Runoff (L). Superelevation runoff is the distance needed to change the cross slope from the end of the tangent runout (adverse cross slope removed) to a section that is sloped at the design superelevation rate (e).

16. Traveled Way. The portion of the roadway used for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

# 29-2 HORIZONTAL CURVES

Horizontal curves are circular arcs that provide transitions between two tangents. The radius (R) defines the circular arc that a curve will transcribe. These deflectional changes are necessary in virtually all roadway alignments to avoid impacts on a variety of field conditions (e.g., right-of-way, natural features, man-made features).

## 29-2.01 Types of Horizontal Curves

Section 29-2.01 discusses the types of horizontal curves that may be used to achieve the necessary roadway deflection.

### 29-2.01(a) Simple Curves

Because of their simplicity and ease of design, survey, and construction, it is strongly recommended to use simple curves on local facilities.

### 29-2.01(b) Compound Curves

The use of compound curves on roadway mainline is recommended only in special circumstances to meet field conditions (e.g., to avoid obstructions that cannot be relocated) where a simple curve cannot meet this need. When a compound curve is used on mainline, the radius of the flatter circular arc ($R_1$) should not be more than 50% greater than the radius of the sharper circular arc ($R_2$). In other words, $R_1 \leq 1.5 R_2$.

Chapter 34 discusses the use of compound curves for intersections at-grade (e.g., for curb radii).

### 29-2.01(c) Reverse Curves

Where reverse curves are used, a distance adequate to provide the superelevation transition should be provided between the PT and PC of the two curves. Superelevation development for reverse curves requires special attention. This is discussed in Section 29-3.

### 29-2.01(d) Broken-Back Curves

Broken-back curves should be avoided on the roadway mainline because of the potential for confusing a driver, problems with superelevation development, and the unpleasant view of the roadway that is created. Instead, it is recommended that a single, flat simple curve be used. In rural and suburban areas, a minimum tangent length of 500 ft (150 m) should be provided between two horizontal curves with deflections in the same direction.

## 29-2.02 Basic Curve Equation

The point-mass formula is used to define vehicular operation around a curve. Where the curve is expressed using its radius, the basic equation for a simple curve is:

$$R = \frac{V^2}{15\,(e + f)} \qquad \text{(US Customary) Equation 29-2.1}$$

$$R = \frac{V^2}{127(e + f)} \qquad \text{(Metric) Equation 29-2.1}$$

where:
- R = radius of curve, ft (m)
- V = design speed, mph (km/h)
- e = superelevation rate, decimal
- f = side friction factor (constant based on design speed)

## 29-2.03 Minimum Radii

Figures 29-2A ($e_{max}$ = 8.0%), 29-2B ($e_{max}$ = 6.0%), and 29-2C ($e_{max}$ = 4.0%) present the minimum radii for open-roadway conditions. See Section 29-3.01 for the selection of $e_{max}$. In most cases, the designer should avoid the use of minimum radii because this results in the use of maximum superelevation rates. These rates should be avoided because the facility must often accommodate vehicles traveling over a wide range of speeds. This is particularly true in Illinois where the entire State is subject to ice and snow. Where vehicular speeds are slow or stopped and the rate of superelevation is high, vehicles could slide down the cross slope when the pavement is icy.

## 29-2.04 Side Friction Factor

The side friction factor (f) represents the contribution of the roadway/tire interface to counterbalance the centrifugal force of a vehicle traversing the curve. This factor varies according to design speed and open-roadway or low-speed urban street conditions. It is important to recognize that the side friction factor represents a threshold of driver discomfort not the point of impending skid. Figure 29-2D presents the side friction factors used in Equation 29.2-1 for open-roadway conditions.

## 29-2.05 Maximum Deflection Without Curve

It may be appropriate to omit a horizontal curve where very small deflection angles are present. As a guide, the designer may retain deflection angles of approximately 1° or less on both rural and urban local agency facilities without providing a horizontal curve. For these angles, the absence of a horizontal curve should not affect operations or aesthetics.

| US Customary | | Metric | |
|---|---|---|---|
| Design Speed (mph) | Minimum Radii, $R_{min}$* (ft) | Design Speed (km/h) | Minimum Radii, $R_{min}$* (m) |
| 20 | 105 | 30 | 30 |
| 25 | 170 | 40 | 50 |
| 30 | 250 | 50 | 80 |
| 35 | 350 | 60 | 125 |
| 40 | 465 | 70 | 175 |
| 45 | 600 | 80 | 230 |
| 50 | 760 | 90 | 305 |
| 55 | 965 | 100 | 395 |
| 60 | 1205 | | |

**MINIMUM RADII**
**($e_{max}$ = 8.0%, Open-Roadway Conditions)**

**Figure 29-2A**

| US Customary | | Metric | |
|---|---|---|---|
| Design Speed (mph) | Minimum Radii, $R_{min}$* (ft) | Design Speed (km/h) | Minimum Radii, $R_{min}$* (m) |
| 20 | 115 | 30 | 30 |
| 25 | 185 | 40 | 55 |
| 30 | 275 | 50 | 90 |
| 35 | 380 | 60 | 135 |
| 40 | 510 | 70 | 195 |
| 45 | 660 | 80 | 250 |
| 50 | 835 | 90 | 335 |
| 55 | 1065 | 100 | 435 |
| 60 | 1340 | | |

**MINIMUM RADII**
**($e_{max}$ = 6.0%, Open-Roadway Conditions)**

**Figure 29-2B**

| **US Customary** | | **Metric** | |
|---|---|---|---|
| Design Speed (mph) | Minimum Radii, $R_{min}$* (ft) | Design Speed (km/h) | Minimum Radii, $R_{min}$* (m) |
| 20 | 125 | 30 | 35 |
| 25 | 205 | 40 | 60 |
| 30 | 300 | 50 | 100 |
| 35 | 420 | 60 | 150 |
| 40 | 565 | 70 | 215 |
| 45 | 730 | 80 | 280 |
| 50 | 930 | 90 | 375 |
| 55 | 1190 | 100 | 490 |
| 60 | 1505 | | |

**MINIMUM RADII**
**($e_{max}$ = 4.0%, Open-Roadway Conditions)**

**Figure 29-2C**

** Values for design have been rounded to the nearest 5 ft (5 m) increment.*

| **US Customary** | | **Metric** | |
|---|---|---|---|
| Design Speed (mph) | Side Friction Factor (f) | Design Speed (km/h) | Side Friction Factor (f) |
| 20 | 0.170 | 30 | 0.17 |
| 25 | 0.165 | 40 | 0.17 |
| 30 | 0.160 | 50 | 0.16 |
| 35 | 0.155 | 60 | 0.15 |
| 40 | 0.150 | 70 | 0.14 |
| 45 | 0.145 | 80 | 0.14 |
| 50 | 0.140 | 90 | 0.13 |
| 55 | 0.130 | 100 | 0.12 |
| 60 | 0.120 | | |

**SIDE FRICTION FACTORS**
**(Open-Roadway Conditions)**

**Figure 29-2D**

## 29-2.06 Minimum Length of Curve

The radius is used to calculate the length of curve by using the following equation:

$$L = \frac{2\pi R\Delta}{360} \qquad \text{Equation 29-2.2}$$

where:

L = length of curve, ft (m)
$\Delta$ = deflection angle, degrees
R = radius of curve, ft (m)

A longer than calculated length of curve may be necessary depending on the design speed. Figure 29-2E provides design values for the minimum length of curve based on design speed.

For small deflection angles, horizontal curves should be sufficiently long to avoid the appearance of a kink. Where the deflection angle is 5° or less, the minimum length of curve should be 500 ft (150 m).

| US Customary | | Metric | |
|---|---|---|---|
| Design Speed, V (mph) | Minimum Length of Curve, L (ft) | Design Speed, V (km/h) | Minimum Length of Curve, L (m) |
| 30 | 100 | 50 | 45 |
| 35 | 150 | 60 | 60 |
| 40 | 200 | 70 | 75 |
| 45 | 250 | 80 | 90 |
| 50 | 300 | 90 | 105 |
| 55 | 350 | 100 | 120 |
| 60 | 400 | | |

**MINIMUM LENGTH OF CURVE**

**Figure 29-2E**

### 29-2.07 Maximum Length of Curve

To improve driver tolerance by reducing steering time in a circular path, the maximum curve length for high-speed, two-lane highways should not exceed 1 mile (1.6 km). On low-speed, two-lane highways, the maximum curve length should be limited to approximately ¼ mile (0.5 km). Lengths in excess of these values should be avoided.

## 29-3 SUPERELEVATION DEVELOPMENT (Open-Roadway Conditions)

This Section presents criteria for superelevation development, which apply to all rural facilities and to urban facilities where V ≥ 50 mph (80 km/h). See Section 29-4 for low-speed urban streets.

### 29-3.01 Superelevation Rates

#### 29-3.01(a) Maximum Superelevation Rate

The selection of a maximum allowable rate of superelevation ($e_{max}$) depends upon several factors. These include urban/rural location, type of existing or expected roadside development, type of pavement surface, and prevalent climatic conditions within Illinois. For open-roadway conditions, the following typical $e_{max}$ values apply:

1. Rural. Use $e_{max}$ = 8.0% for all rural facilities, except for facilities with aggregate surfaces.
2. Urban/Suburban. Where V ≥ 50 mph (80 km/h), use $e_{max}$ = 6.0% for urban/suburban facilities.
3. Aggregate Surface. For rural facilities with an aggregate surface, use $e_{max}$ = 4.0%.

For Items 1 and 2, the designer may use a lower $e_{max}$.

#### 29-3.01(b) Superelevation Tables

Based on the selection of $e_{max}$, Figures 29-3A, 29-3B, and 29-3C allow the designer to select the appropriate superelevation rate (e) for any combination of curve radius (R) and design speed (V). Note that the superelevation rates in the figures are expressed as a percent.

#### 29-3.01(c) Use of Normal Crown (NC) and Remove Adverse Crown (RC)

A horizontal curve with a sufficiently large radius does not require superelevation, and the normal crown section (NC) used on tangent can be maintained throughout the curve. On sharper curves for the same design speed, a point is reached where a superelevation rate of 1.5% across the total traveled way is appropriate. This is called “remove adverse crown” (RC). Figures 29-3A, 29-3B, and 29-3C indicate the radii ranges where NC and RC apply.

| e | V = 20 mph | | | V = 25 mph | | | V = 30 mph | | | V = 35 mph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 1690 | 0 | 0 | R ≥ 2590 | 0 | 0 | R ≥ 3390 | 0 | 0 | R ≥ 4410 | 0 | 0 |
| RC | 1690 > R ≥ 1230 | 22 | 22 | 2590 > R ≥ 1890 | 24 | 24 | 3390 > R ≥ 2480 | 25 | 25 | 4410 > R ≥ 3230 | 27 | 27 |
| 2.5% | 1230 > R ≥ 950 | 37 | 22 | 1890 > R ≥ 1350 | 39 | 24 | 2480 > R ≥ 1900 | 42 | 25 | 3230 > R ≥ 2500 | 44 | 27 |
| 3.0% | 950 > R ≥ 770 | 45 | 22 | 1350 > R ≥ 1120 | 47 | 24 | 1900 > R ≥ 1530 | 50 | 25 | 2500 > R ≥ 2000 | 53 | 27 |
| 3.5% | 770 > R ≥ 630 | 52 | 22 | 1120 > R ≥ 900 | 55 | 24 | 1530 > R ≥ 1250 | 59 | 25 | 2000 > R ≥ 1670 | 62 | 27 |
| 4.0% | 630 > R ≥ 520 | 59 | 22 | 900 > R ≥ 780 | 63 | 24 | 1250 > R ≥ 1070 | 67 | 25 | 1670 > R ≥ 1400 | 71 | 27 |
| 4.5% | 520 > R ≥ 440 | 67 | 22 | 780 > R ≥ 660 | 71 | 24 | 1070 > R ≥ 900 | 75 | 25 | 1400 > R ≥ 1200 | 80 | 27 |
| 5.0% | 440 > R ≥ 380 | 74 | 22 | 660 > R ≥ 560 | 79 | 24 | 900 > R ≥ 780 | 84 | 25 | 1200 > R ≥ 1030 | 89 | 27 |
| 5.5% | 380 > R ≥ 310 | 82 | 22 | 560 > R ≥ 470 | 87 | 24 | 780 > R ≥ 660 | 92 | 25 | 1030 > R ≥ 900 | 97 | 27 |
| 6.0% | 310 > R ≥ 260 | 89 | 22 | 470 > R ≥ 400 | 94 | 24 | 660 > R ≥ 570 | 100 | 25 | 900 > R ≥ 780 | 106 | 27 |
| 6.5% | 260 > R ≥ 220 | 97 | 22 | 400 > R ≥ 340 | 102 | 24 | 570 > R ≥ 480 | 109 | 25 | 780 > R ≥ 660 | 115 | 27 |
| 7.0% | 220 > R ≥ 180 | 104 | 22 | 340 > R ≥ 280 | 110 | 24 | 480 > R ≥ 410 | 117 | 25 | 660 > R ≥ 570 | 124 | 27 |
| 7.5% | 180 > R ≥ 150 | 111 | 22 | 280 > R ≥ 240 | 118 | 24 | 410 > R ≥ 350 | 125 | 25 | 570 > R ≥ 480 | 133 | 27 |
| 8.0% | 150 > R ≥ 105 | 119 | 22 | 240 > R ≥ 170 | 126 | 24 | 350 > R ≥ 250 | 134 | 25 | 480 > R ≥ 350 | 142 | 27 |
| | $R_{min}$ = 105 ft | | | $R_{min}$ = 170 ft | | | $R_{min}$ = 250 ft | | | $R_{min}$ = 350 ft | | |

| e | V = 40 mph | | | V = 45 mph | | | V = 50 mph | | | V = 55 mph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 5580 | 0 | 0 | R ≥ 6830 | 0 | 0 | R ≥ 8080 | 0 | 0 | R ≥ 9470 | 0 | 0 |
| RC | 5580 > R ≥ 4100 | 28 | 28 | 6830 > R ≥ 5020 | 31 | 31 | 8080 > R ≥ 5940 | 33 | 33 | 9470 > R ≥ 6970 | 35 | 35 |
| 2.5% | 4100 > R ≥ 3170 | 47 | 28 | 5020 > R ≥ 3830 | 51 | 31 | 5940 > R ≥ 4800 | 55 | 33 | 6970 > R ≥ 5750 | 59 | 35 |
| 3.0% | 3170 > R ≥ 2500 | 57 | 28 | 3830 > R ≥ 3130 | 61 | 31 | 4800 > R ≥ 3830 | 66 | 33 | 5750 > R ≥ 4670 | 70 | 35 |
| 3.5% | 2500 > R ≥ 2140 | 66 | 28 | 3130 > R ≥ 2670 | 71 | 31 | 3830 > R ≥ 3200 | 77 | 33 | 4670 > R ≥ 3880 | 82 | 35 |
| 4.0% | 2140 > R ≥ 1800 | 76 | 28 | 2670 > R ≥ 2290 | 81 | 31 | 3200 > R ≥ 2750 | 88 | 33 | 3880 > R ≥ 3300 | 94 | 35 |
| 4.5% | 1800 > R ≥ 1550 | 85 | 28 | 2290 > R ≥ 1930 | 92 | 31 | 2750 > R ≥ 2380 | 99 | 33 | 3300 > R ≥ 2860 | 105 | 35 |
| 5.0% | 1550 > R ≥ 1330 | 95 | 28 | 1930 > R ≥ 1680 | 102 | 31 | 2380 > R ≥ 2060 | 110 | 33 | 2860 > R ≥ 2500 | 117 | 35 |
| 5.5% | 1330 > R ≥ 1170 | 104 | 28 | 1680 > R ≥ 1450 | 112 | 31 | 2060 > R ≥ 1800 | 121 | 33 | 2500 > R ≥ 2220 | 129 | 35 |
| 6.0% | 1170 > R ≥ 1000 | 114 | 28 | 1450 > R ≥ 1270 | 122 | 31 | 1800 > R ≥ 1560 | 132 | 33 | 2220 > R ≥ 1950 | 141 | 35 |
| 6.5% | 1000 > R ≥ 875 | 123 | 28 | 1270 > R ≥ 1100 | 132 | 31 | 1560 > R ≥ 1370 | 143 | 33 | 1950 > R ≥ 1700 | 152 | 35 |
| 7.0% | 875 > R ≥ 750 | 132 | 28 | 1100 > R ≥ 950 | 142 | 31 | 1370 > R ≥ 1200 | 154 | 33 | 1700 > R ≥ 1480 | 164 | 35 |
| 7.5% | 750 > R ≥ 625 | 142 | 28 | 950 > R ≥ 830 | 153 | 31 | 1200 > R ≥ 1030 | 165 | 33 | 1480 > R ≥ 1280 | 176 | 35 |
| 8.0% | 625 > R ≥ 465 | 151 | 28 | 830 > R ≥ 600 | 163 | 31 | 1030 > R ≥ 760 | 176 | 33 | 1280 > R ≥ 965 | 187 | 35 |
| | $R_{min}$ = 465 ft | | | $R_{min}$ = 600 ft | | | $R_{min}$ = 760 ft | | | $R_{min}$ =965 ft | | |

| e | V = 60 mph | | |
|---|---|---|---|
| | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 11,150 | 0 | 0 |
| RC | 11,150 > R ≥ 8220 | 37 | 37 |
| 2.5% | 8220 > R ≥ 6670 | 61 | 37 |
| 3.0% | 6670 > R ≥ 5400 | 73 | 37 |
| 3.5% | 5400 > R ≥ 4570 | 85 | 37 |
| 4.0% | 4570 > R ≥ 3900 | 98 | 37 |
| 4.5% | 3900 > R ≥ 3420 | 110 | 37 |
| 5.0% | 3420 > R ≥ 3000 | 122 | 37 |
| 5.5% | 3000 > R ≥ 2640 | 134 | 37 |
| 6.0% | 2640> R ≥ 2330 | 147 | 37 |
| 6.5% | 2330 > R ≥ 2060 | 159 | 37 |
| 7.0% | 2060 > R ≥ 1840 | 171 | 37 |
| 7.5% | 1840 > R ≥ 1600 | 183 | 37 |
| 8.0% | 1600 > R ≥ 1210 | 195 | 37 |
| | $R_{min}$ = 1210 ft | | |

Key:

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

$e_{max}$ = 8%

**SUPERELEVATION RATES/TRANSITION LENGTHS (US Customary)**

**Figure 29-3A**

| e | V = 30 km/h | | | V = 40 km/h | | | V = 50 km/h | | | V = 60 km/h | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 440 | 0 | 0 | R ≥ 780 | 0 | 0 | R ≥ 1085 | 0 | 0 | R ≥ 1495 | 0 | 0 |
| RC | 440 > R ≥ 325 | 7 | 7 | 780 > R ≥ 570 | 7 | 7 | 1085 > R ≥ 795 | 7 | 7 | 1495 > R ≥ 1095 | 8 | 8 |
| 2.5% | 325 > R ≥ 250 | 11 | 7 | 570 > R ≥ 440 | 12 | 7 | 795 > R ≥ 625 | 12 | 7 | 1095 > R ≥ 865 | 14 | 8 |
| 3.0% | 250 > R ≥ 200 | 13 | 7 | 440 > R ≥ 355 | 14 | 7 | 625 > R ≥ 500 | 15 | 7 | 865 > R ≥ 700 | 17 | 8 |
| 3.5% | 200 > R ≥ 170 | 15 | 7 | 355 > R ≥ 290 | 17 | 7 | 500 > R ≥ 415 | 17 | 7 | 700 > R ≥ 580 | 19 | 8 |
| 4.0% | 170 > R ≥ 140 | 18 | 7 | 290 > R ≥ 250 | 19 | 7 | 415 > R ≥ 355 | 20 | 7 | 580 > R ≥ 490 | 22 | 8 |
| 4.5% | 140 > R ≥ 115 | 20 | 7 | 250 > R ≥ 210 | 21 | 7 | 355 > R ≥ 300 | 22 | 7 | 490 > R ≥ 425 | 25 | 8 |
| 5.0% | 115 > R ≥ 100 | 22 | 7 | 210 > R ≥ 175 | 24 | 7 | 300 > R ≥ 260 | 25 | 7 | 425 > R ≥ 365 | 28 | 8 |
| 5.5% | 100 > R ≥ 80 | 24 | 7 | 175 > R ≥ 145 | 26 | 7 | 260 > R ≥ 220 | 27 | 7 | 365 > R ≥ 310 | 30 | 8 |
| 6.0% | 80 > R ≥ 70 | 26 | 7 | 145 > R ≥ 120 | 28 | 7 | 220 > R ≥ 190 | 30 | 7 | 310 > R ≥ 265 | 33 | 8 |
| 6.5% | 70 > R ≥ 60 | 29 | 7 | 120 > R ≥ 105 | 31 | 7 | 190 > R ≥ 160 | 32 | 7 | 265 > R ≥ 230 | 36 | 8 |
| 7.0% | 60 > R ≥ 50 | 31 | 7 | 105 > R ≥ 85 | 33 | 7 | 160 > R ≥ 135 | 35 | 7 | 230 > R ≥ 200 | 39 | 8 |
| 7.5% | 50 > R ≥ 40 | 33 | 7 | 85 > R ≥ 70 | 35 | 7 | 135 > R ≥ 115 | 37 | 7 | 200 > R ≥ 170 | 41 | 8 |
| 8.0% | 40 > R ≥ 28 | 35 | 7 | 70 > R ≥ 50 | 38 | 7 | 115 > R ≥ 82 | 40 | 7 | 170 > R ≥ 123 | 44 | 8 |
| | $R_{min}$ = 28 m | | | $R_{min}$ = 50 m | | | $R_{min}$ = 82 m | | | $R_{min}$ = 123 m | | |

| e | V = 70 km/h | | | V = 80 km/h | | | V = 90 km/h | | | V = 100 km/h | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 1965 | 0 | 0 | R ≥ 2435 | 0 | 0 | R ≥ 2960 | 0 | 0 | R ≥ 3625 | 0 | 0 |
| RC | 1965 > R ≥ 1445 | 9 | 9 | 2435 > R ≥ 1790 | 10 | 10 | 2960 > R ≥ 2180 | 11 | 11 | 3625 > R ≥ 2675 | 11 | 11 |
| 2.5% | 1445 > R ≥ 1150 | 15 | 9 | 1790 > R ≥ 1400 | 17 | 10 | 2180 > R ≥ 1750 | 18 | 11 | 2675 > R ≥ 2100 | 19 | 11 |
| 3.0% | 1150 > R ≥ 930 | 18 | 9 | 1400 > R ≥ 1160 | 20 | 10 | 1750 > R ≥ 1400 | 21 | 11 | 2100 > R ≥ 1750 | 22 | 11 |
| 3.5% | 930 > R ≥ 775 | 21 | 9 | 1160 > R ≥ 965 | 23 | 10 | 1400 > R ≥ 1165 | 25 | 11 | 1750 > R ≥ 1450 | 26 | 11 |
| 4.0% | 775 > R ≥ 660 | 24 | 9 | 965 > R ≥ 825 | 26 | 10 | 1165 > R ≥ 1000 | 28 | 11 | 1450> R ≥ 1235 | 30 | 11 |
| 4.5% | 660 > R ≥ 565 | 27 | 9 | 825 > R ≥ 700 | 30 | 10 | 1000 > R ≥ 875 | 32 | 11 | 1235> R ≥ 1085 | 34 | 11 |
| 5.0% | 565 > R ≥ 490 | 30 | 9 | 700 > R ≥ 615 | 33 | 10 | 875 > R ≥ 760 | 35 | 11 | 1085 > R ≥ 950 | 37 | 11 |
| 5.5% | 490 > R ≥ 425 | 33 | 9 | 615 > R ≥ 545 | 36 | 10 | 760 > R ≥ 670 | 39 | 11 | 950 > R ≥ 840 | 41 | 11 |
| 6.0% | 425 > R ≥ 370 | 36 | 9 | 545 > R ≥ 475 | 40 | 10 | 670 > R ≥ 600 | 42 | 11 | 840 > R ≥ 750 | 45 | 11 |
| 6.5% | 370 > R ≥ 320 | 39 | 9 | 475 > R ≥ 415 | 43 | 10 | 600 > R ≥ 530 | 46 | 11 | 750 > R ≥ 665 | 49 | 11 |
| 7.0% | 320 > R ≥ 280 | 42 | 9 | 415 > R ≥ 360 | 46 | 10 | 530 > R ≥ 465 | 49 | 11 | 665 > R ≥ 585 | 52 | 11 |
| 7.5% | 280 > R ≥ 240 | 45 | 9 | 360 R ≥ 310 | 50 | 10 | 465 > R ≥ 400 | 53 | 11 | 585 > R ≥ 515 | 56 | 11 |
| 8.0% | 240 > R ≥ 175 | 48 | 9 | 310 > R ≥ 229 | 53 | 10 | 400 > R ≥ 304 | 56 | 11 | 515 > R ≥ 394 | 60 | 11 |
| | $R_{min}$ = 175 m | | | $R_{min}$ = 229 m | | | $R_{min}$ = 304 m | | | $R_{min}$ = 394 m | | |

Key:

$e_{max}$ = 8%

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

**SUPERELEVATION RATES/TRANSITION LENGTHS (Metric)**

**Figure 29-3A**

| e | V = 20 mph | | | V = 25 mph | | | V = 30 mph | | | V = 35 mph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 1630 | 0 | 0 | R ≥ 2490 | 0 | 0 | R ≥ 3270 | 0 | 0 | R ≥ 4260 | 0 | 0 |
| RC | 1630 > R ≥ 1160 | 22 | 22 | 2490 > R ≥ 1790 | 24 | 24 | 3270 > R ≥ 2350 | 25 | 25 | 4260 > R ≥ 3070 | 27 | 27 |
| 2.5% | 1160 > R ≥ 870 | 37 | 22 | 1790 > R ≥ 1270 | 39 | 24 | 2350 > R ≥ 1730 | 42 | 25 | 3070 > R ≥ 2300 | 44 | 27 |
| 3.0% | 870 > R ≥ 670 | 45 | 22 | 1270 > R ≥ 1000 | 47 | 24 | 1730 > R ≥ 1350 | 50 | 25 | 2300 > R ≥ 1800 | 53 | 27 |
| 3.5% | 670 > R ≥ 530 | 52 | 22 | 1000 > R ≥ 770 | 55 | 24 | 1350 > R ≥ 1100 | 59 | 25 | 1800 > R ≥ 1470 | 62 | 27 |
| 4.0% | 530 > R ≥ 400 | 59 | 22 | 770 > R ≥ 600 | 63 | 24 | 1100 > R ≥ 850 | 67 | 25 | 1470 > R ≥ 1150 | 71 | 27 |
| 4.5% | 400 > R ≥ 300 | 67 | 22 | 600 > R ≥ 450 | 71 | 24 | 850 > R ≥ 670 | 75 | 25 | 1150 > R ≥ 900 | 80 | 27 |
| 5.0% | 300 > R ≥ 230 | 74 | 22 | 450 > R ≥ 370 | 79 | 24 | 670 > R ≥ 530 | 84 | 25 | 900 > R ≥ 730 | 89 | 27 |
| 5.5% | 230 > R ≥ 180 | 82 | 22 | 370 > R ≥ 280 | 87 | 24 | 530 > R ≥ 420 | 92 | 25 | 730 > R ≥ 570 | 97 | 27 |
| 6.0% | 180 > R ≥ 115 | 89 | 22 | 280 > R ≥ 185 | 94 | 24 | 420 > R ≥ 275 | 100 | 25 | 570 > R ≥ 380 | 106 | 27 |
| | $R_{min}$ = 115 ft | | | $R_{min}$ = 185 ft | | | $R_{min}$ = 275 ft | | | $R_{min}$ = 380 ft | | |

| e | V = 40 mph | | | V = 45 mph | | | V = 50 mph | | | V = 55 mph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 5400 | 0 | 0 | R ≥ 6610 | 0 | 0 | R ≥ 7820 | 0 | 0 | R ≥ 9170 | 0 | 0 |
| RC | 5400 > R ≥ 3900 | 28 | 28 | 6610 > R ≥ 4780 | 31 | 31 | 7820 > R ≥ 5660 | 33 | 33 | 9170 > R ≥ 6660 | 35 | 35 |
| 2.5% | 3900 > R ≥ 2880 | 47 | 28 | 4780 > R ≥ 3670 | 51 | 31 | 5660 > R ≥ 4400 | 55 | 33 | 6660 > R ≥ 5250 | 59 | 35 |
| 3.0% | 2880 > R ≥ 2300 | 57 | 28 | 3670 > R ≥ 2880 | 61 | 31 | 4400 > R ≥ 3500 | 66 | 33 | 5250 > R ≥ 4200 | 70 | 35 |
| 3.5% | 2300 > R ≥ 1870 | 66 | 28 | 2880 > R ≥ 2300 | 71 | 31 | 3500 > R ≥ 2880 | 77 | 33 | 4200 > R ≥ 3500 | 82 | 35 |
| 4.0% | 1870 > R ≥ 1470 | 76 | 28 | 2300 > R ≥ 1870 | 81 | 31 | 2880 > R ≥ 2300 | 88 | 33 | 3500 > R ≥ 2880 | 94 | 35 |
| 4.5% | 1470 > R ≥ 1200 | 85 | 28 | 1870 > R ≥ 1530 | 92 | 31 | 2300 > R ≥ 1870 | 99 | 33 | 2880 > R ≥ 2330 | 105 | 35 |
| 5.0% | 1200 > R ≥ 950 | 95 | 28 | 1530 > R ≥ 1200 | 102 | 31 | 1870 > R ≥ 1530 | 110 | 33 | 2330 > R ≥ 1900 | 117 | 35 |
| 5.5% | 950 > R ≥ 770 | 104 | 28 | 1200 > R ≥ 1000 | 112 | 31 | 1530 > R ≥ 1250 | 121 | 33 | 1900 > R ≥ 1530 | 129 | 35 |
| 6.0% | 770 > R ≥ 510 | 114 | 28 | 1000 > R ≥ 660 | 122 | 31 | 1250 > R ≥ 835 | 132 | 33 | 1530 > R ≥ 1065 | 141 | 35 |
| | $R_{min}$ = 510 ft | | | $R_{min}$ = 660 ft | | | $R_{min}$ = 835 ft | | | $R_{min}$ = 1065 ft | | |

| e | V = 60 mph | | |
|---|---|---|---|
| | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 10,810 | 0 | 0 |
| RC | 10,810 > R ≥ 7860 | 37 | 37 |
| 2.5% | 7860 > R ≥ 6310 | 61 | 37 |
| 3.0% | 6310 > R ≥ 5000 | 73 | 37 |
| 3.5% | 5000 > R ≥ 4170 | 85 | 37 |
| 4.0% | 4170 > R ≥ 3380 | 98 | 37 |
| 4.5% | 3380 > R ≥ 2800 | 110 | 37 |
| 5.0% | 2800 > R ≥ 2330 | 122 | 37 |
| 5.5% | 2330 > R ≥ 1900 | 134 | 37 |
| 6.0% | 1900 > R ≥ 1340 | 147 | 37 |
| | $R_{min}$ = 1340 ft | | |

Key:

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

$e_{max}$ = 6%

**SUPERELEVATION RATES/TRANSITION LENGTHS (US Customary)**

**Figure 29-3B**

| e | V = 30 km/h | | | V = 40 km/h | | | V = 50 km/h | | | V = 60 km/h | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 425 | 0 | 0 | R ≥ 755 | 0 | 0 | R ≥ 1050 | 0 | 0 | R ≥ 1440 | 0 | 0 |
| RC | 425 > R ≥ 305 | 7 | 7 | 755 > R ≥ 540 | 7 | 7 | 1050 > R ≥ 755 | 7 | 7 | 1440 > R ≥ 1040 | 8 | 8 |
| 2.5% | 305> R ≥ 230 | 11 | 7 | 540 > R ≥ 400 | 12 | 7 | 755 > R ≥ 585 | 12 | 7 | 1040 > R ≥ 800 | 14 | 8 |
| 3.0% | 230 > R ≥ 175 | 13 | 7 | 400 > R ≥ 315 | 14 | 7 | 585 > R ≥ 460 | 15 | 7 | 800 > R ≥ 635 | 17 | 8 |
| 3.5% | 175 > R ≥ 140 | 15 | 7 | 315 > R ≥ 250 | 17 | 7 | 460 > R ≥ 365 | 17 | 7 | 635 > R ≥ 500 | 19 | 8 |
| 4.0% | 140 > R ≥ 105 | 18 | 7 | 250 > R ≥ 190 | 19 | 7 | 365 > R ≥ 285 | 20 | 7 | 500 > R ≥ 400 | 22 | 8 |
| 4.5% | 105 > R ≥ 80 | 20 | 7 | 190 > R ≥ 140 | 21 | 7 | 285 > R ≥ 220 | 22 | 7 | 400 > R ≥ 315 | 25 | 8 |
| 5.0% | 80 > R ≥ 60 | 22 | 7 | 140 > R ≥ 110 | 24 | 7 | 220 > R ≥ 175 | 25 | 7 | 315 > R ≥ 250 | 28 | 8 |
| 5.5% | 60 > R ≥ 50 | 24 | 7 | 110 > R ≥ 85 | 26 | 7 | 175 > R ≥ 135 | 27 | 7 | 250 > R ≥ 200 | 30 | 8 |
| 6.0% | 50 > R ≥ 31 | 26 | 7 | 85 > R ≥ 55 | 28 | 7 | 135 > R ≥ 89 | 30 | 7 | 200 > R ≥ 135 | 33 | 8 |
| | $R_{min}$ = 31 m | | | $R_{min}$ = 55 m | | | $R_{min}$ = 89 m | | | $R_{min}$ = 135 m | | |

| e | V = 70 km/h | | | V = 80 km/h | | | V = 90 km/h | | | V = 100 km/h | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 1900 | 0 | 0 | R ≥ 2355 | 0 | 0 | R ≥ 2870 | 0 | 0 | R ≥ 3515 | 0 | 0 |
| RC | 1900 > R ≥ 1375 | 9 | 9 | 2355 > R ≥ 1705 | 10 | 10 | 2870 > R ≥ 2085 | 11 | 11 | 3515 > R ≥ 2560 | 11 | 11 |
| 2.5% | 1375 > R ≥ 1050 | 15 | 9 | 1705 > R ≥ 1300 | 17 | 10 | 2085 > R ≥ 1665 | 18 | 11 | 2560 > R ≥ 2000 | 19 | 11 |
| 3.0% | 1050 > R ≥ 835 | 18 | 9 | 1300 > R ≥ 1050 | 20 | 10 | 1665 > R ≥ 1300 | 21 | 11 | 2000 > R ≥ 1585 | 22 | 11 |
| 3.5% | 835 > R ≥ 675 | 21 | 9 | 1050 > R ≥ 850 | 23 | 10 | 1300 > R ≥ 1050 | 25 | 11 | 1585 > R ≥ 1300 | 26 | 11 |
| 4.0% | 675 > R ≥ 550 | 24 | 9 | 850 > R ≥ 700 | 26 | 10 | 1050 > R ≥ 865 | 28 | 11 | 1300 > R ≥ 1080 | 30 | 11 |
| 4.5% | 550 > R ≥ 440 | 27 | 9 | 700 > R ≥ 560 | 30 | 10 | 865 > R ≥ 725 | 32 | 11 | 1080 > R ≥ 900 | 34 | 11 |
| 5.0% | 440 > R ≥ 355 | 30 | 9 | 560 > R ≥ 460 | 33 | 10 | 725 > R ≥ 600 | 35 | 11 | 900 > R ≥ 765 | 37 | 11 |
| 5.5% | 355 > R ≥ 290 | 33 | 9 | 460 > R ≥ 365 | 36 | 10 | 600 > R ≥ 480 | 39 | 11 | 765 > R ≥ 625 | 41 | 11 |
| 6.0% | 290 > R ≥ 193 | 36 | 9 | 365 > R ≥ 252 | 40 | 10 | 480 > R ≥ 336 | 42 | 11 | 625 > R ≥ 437 | 45 | 11 |
| | $R_{min}$ = 193 m | | | $R_{min}$ = 252 m | | | $R_{min}$ = 336 m | | | $R_{min}$ = 437 m | | |

Key:

$e_{max}$ = 6%

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

**SUPERELEVATION RATES/TRANSITION LENGTHS (Metric)**

**Figure 29-3B**

| e | V = 20 mph | | | V = 25 mph | | | V = 30 mph | | | V = 35 mph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 1480 | 0 | 0 | R ≥ 2260 | 0 | 0 | R ≥ 2980 | 0 | 0 | R ≥ 3890 | 0 | 0 |
| RC | 1480 > R ≥ 980 | 22 | 22 | 2260 > R ≥ 1500 | 24 | 24 | 2980 > R ≥ 2000 | 25 | 25 | 3890 > R ≥ 2630 | 27 | 27 |
| 2.5% | 980 > R ≥ 600 | 37 | 22 | 1500 > R ≥ 900 | 39 | 24 | 2000 > R ≥ 1200 | 42 | 25 | 2630 > R ≥ 1700 | 44 | 27 |
| 3.0% | 600 > R ≥ 350 | 45 | 22 | 900 > R ≥ 550 | 47 | 24 | 1200 > R ≥ 800 | 50 | 25 | 1700 > R ≥ 1100 | 53 | 27 |
| 3.5% | 350 > R ≥ 230 | 52 | 22 | 550 > R ≥ 380 | 55 | 24 | 800 > R ≥ 550 | 59 | 25 | 1100 > R ≥ 750 | 62 | 27 |
| 4.0% | 230 > R ≥ 125 | 59 | 22 | 380 > R ≥ 205 | 63 | 24 | 550 > R ≥ 300 | 67 | 25 | 750 > R ≥ 420 | 71 | 27 |
| | $R_{min}$ = 125 ft | | | $R_{min}$ = 205 ft | | | $R_{min}$ = 300 ft | | | $R_{min}$ = 420 ft | | |

| e | V = 40 mph | | | V = 45 mph | | | V = 50 mph | | | V = 55 mph | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 4940 | 0 | 0 | R ≥ 6060 | 0 | 0 | R ≥ 7550 | 0 | 0 | R ≥ 8700 | 0 | 0 |
| RC | 4940 > R ≥ 3360 | 28 | 28 | 6060 > R ≥ 4140 | 31 | 31 | 7550 > R ≥ 5150 | 33 | 33 | 8700 > R ≥ 5960 | 35 | 35 |
| 2.5% | 3360 > R ≥ 2250 | 47 | 28 | 4140 > R ≥ 2750 | 51 | 31 | 5150 > R ≥ 3540 | 55 | 33 | 5960 > R ≥ 4220 | 59 | 35 |
| 3.0% | 2250 > R ≥ 1400 | 57 | 28 | 2750 > R ≥ 1800 | 61 | 31 | 3540 > R ≥ 2330 | 66 | 33 | 4220 > R ≥ 2880 | 70 | 35 |
| 3.5% | 1400 > R ≥ 1000 | 66 | 28 | 1800 > R ≥ 1300 | 71 | 31 | 2330 > R ≥ 1610 | 77 | 33 | 2880 > R ≥ 2030 | 82 | 35 |
| 4.0% | 1000 > R ≥ 565 | 76 | 28 | 1300 > R ≥ 730 | 81 | 31 | 1610 > R ≥ 930 | 88 | 33 | 2030 > R ≥ 1190 | 94 | 35 |
| | | | | | | | | | | | | |
| | $R_{min}$ = 565 ft | | | $R_{min}$ = 730 ft | | | $R_{min}$ = 930 ft | | | $R_{min}$ = 1190 ft | | |

| e | V = 60 mph | | |
|---|---|---|---|
| | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 10,290 | 0 | 0 |
| RC | 10,290 > R ≥ 7130 | 37 | 37 |
| 2.5% | 7130 > R ≥ 5090 | 61 | 37 |
| 3.0% | 5090 > R ≥ 3550 | 73 | 37 |
| 3.5% | 3550 > R ≥ 2540 | 85 | 37 |
| 4.0% | 2540 > R ≥ 1505 | 98 | 37 |
| | $R_{min}$ = 1505 ft | | |

Key:

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

$e_{max}$ = 4%

**SUPERELEVATION RATES/TRANSITION LENGTHS (US Customary)**

**Figure 29-3C**

| e | V = 30 km/h | | | V = 40 km/h | | | V = 50 km/h | | | V = 60 km/h | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 385 | 0 | 0 | R ≥ 680 | 0 | 0 | R ≥ 955 | 0 | 0 | R ≥ 1320 | 0 | 0 |
| RC | 385 > R ≥ 255 | 11 | 7 | 680 > R ≥ 450 | 7 | 7 | 955 > R ≥ 640 | 7 | 7 | 1320 > R ≥ 895 | 8 | 8 |
| 2.5% | 255 > R ≥ 150 | 13 | 7 | 450 > R ≥ 275 | 12 | 7 | 640 > R ≥ 400 | 12 | 7 | 895 > R ≥ 600 | 14 | 8 |
| 3.0% | 150 > R ≥ 90 | 15 | 7 | 275 > R ≥ 165 | 14 | 7 | 400 > R ≥ 250 | 15 | 7 | 600 > R ≥ 400 | 17 | 8 |
| 3.5% | 90 > R ≥ 60 | 18 | 7 | 165 > R ≥ 110 | 17 | 7 | 250 > R ≥ 175 | 17 | 7 | 400 > R ≥ 265 | 19 | 8 |
| 4.0% | 60 > R ≥ 34 | 20 | 7 | 110 > R ≥ 60 | 19 | 7 | 175 > R ≥ 98 | 20 | 7 | 265 > R ≥ 149 | 22 | 8 |
| | $R_{min}$ = 34 m | | | $R_{min}$ = 60 m | | | $R_{min}$ = 98 m | | | $R_{min}$ = 149 m | | |

| e | V = 70 km/h | | | V = 80 km/h | | | V = 90 km/h | | | V = 100 km/h | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 1745 | 0 | 0 | R ≥ 2145 | 0 | 0 | R ≥ 2650 | 0 | 0 | R ≥ 3250 | 0 | 0 |
| RC | 1745 > R ≥ 1190 | 9 | 9 | 2145 > R ≥ 1460 | 10 | 10 | 2650 > R ≥ 1830 | 11 | 11 | 3250 > R ≥ 2260 | 11 | 11 |
| 2.5% | 1190 > R ≥ 800 | 15 | 9 | 1460 > R ≥ 985 | 17 | 10 | 1830 > R ≥ 1300 | 18 | 11 | 2260 > R ≥ 1625 | 19 | 11 |
| 3.0% | 800 > R ≥ 550 | 18 | 9 | 985 > R ≥ 645 | 20 | 10 | 1300 > R ≥ 900 | 21 | 11 | 1625 > R ≥ 1150 | 22 | 11 |
| 3.5% | 550 > R ≥ 375 | 21 | 9 | 645 > R ≥ 445 | 23 | 10 | 900 > R ≥ 635 | 25 | 11 | 1150 > R ≥ 830 | 26 | 11 |
| 4.0% | 375 > R ≥ 214 | 24 | 9 | 445 > R ≥ 280 | 26 | 10 | 635 > R ≥ 375 | 28 | 11 | 830> R ≥ 490 | 30 | 11 |
| | $R_{min}$ = 214 m | | | $R_{min}$ = 280 m | | | $R_{min}$ = 375 m | | | $R_{min}$ = 490 m | | |

$e_{max}$ = 4%

Key:

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

**SUPERELEVATION RATES/TRANSITION LENGTHS (Metric)**

**Figure 29-3C**

## 29-3.02 Transition Lengths

As defined in Section 29-1, the superelevation transition length is the distance required to transition the roadway from a normal crown section to the full design superelevation rate. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length ($L_1$).

### 29-3.02(a) Two-Lane Roadways

1. Superelevation Runoff. The $e_{max}$ tables (Figures 29-3A, 29-3B, and 29-3C) present the superelevation runoff lengths ($L_1$) for two-lane roadways for various combinations of curve radii and design speed. These lengths are calculated as follows:

   $$L_1 = (e)(W)(RS) \qquad \text{Equation 29-3.1}$$

   where: $L_1$ = superelevation runoff length for a two-lane roadway (assuming the axis of rotation is about the roadway centerline), ft (m)

   e = design superelevation rate (ft/ft (m/m)), decimal

   W = width of rotation for one lane (assumed to be 11 ft (3.3 m))

   RS = reciprocal of relative longitudinal gradient between the profile grade and outside edge of two-lane roadway; see Figure 29-3D

2. Tangent Runout. The tangent runout (TR) distance should be calculated using the tangent cross slope and the maximum relative longitudinal gradient based on the selected design speed; as shown in Figure 29-3D. TR is calculated as follows:

   $$TR = (NC)(W)(RS) \qquad \text{Equation 29-3.2}$$

   where: TR = tangent runout length for a two-lane roadway, (assuming the axis of rotation is about the roadway centerline), ft (m)

   NC = normal crown slope (assumed to be 0.015 ft/ft (m/m)), decimal

   W = width of rotation for one lane (assumed to be 11 ft (3.3 m))

   RS = reciprocal of relative longitudinal gradient between the profile grade and outside edge of two-lane roadway; see Figure 29-3D

| US Customary | | | Metric | | |
|---|---|---|---|---|---|
| Design Speed (mph) | Maximum Relative (G) Gradient (%) | Reciprocal (RS) | Design Speed (km/h) | Maximum Relative (G) Gradient (%) | Reciprocal (RS) |
| 20 | 0.74 | 135 | 30 | 0.75 | 133 |
| 25 | 0.70 | 143 | 40 | 0.70 | 143 |
| 30 | 0.66 | 152 | 50 | 0.65 | 150 |
| 35 | 0.62 | 161 | 60 | 0.60 | 167 |
| 40 | 0.58 | 172 | 70 | 0.55 | 182 |
| 45 | 0.54 | 185 | 80 | 0.50 | 200 |
| 50 | 0.50 | 200 | 90 | 0.47 | 213 |
| 55 | 0.47 | 213 | 100 | 0.44 | 227 |
| 60 | 0.45 | 222 | | | |

**MAXIMUM RELATIVE LONGITUDINAL GRADIENTS**

**Figure 29-3D**

3. Superelevation Transition Length. The total of the tangent runout (TR) distance and superelevation runoff length ($L_1$) equals the minimum superelevation transition length used for a two-lane roadway at an isolated horizontal curve.

### 29-3.02(b) Multilane Roadways

For superelevation transition lengths for multilane roadways, see Section 32-3 of the *BDE Manual*.

### 29-3.02(c) Application of Transition Length

Once the superelevation runoff and tangent runout have been calculated, the designer must determine how to fit the length into the horizontal and vertical planes. The following will apply:

1. Tangent/Curve. To simplify procedures, the total superelevation transition length should be distributed to be 75% on tangent and 25% on the curve. However, exceptions to this practice may be necessary to meet field conditions. The generally accepted range is 50% to 80% on tangent and 20% to 50% on curve. In extreme cases (e.g., to avoid placing any superelevation transition on a bridge or approach slab), the superelevation runoff may be distributed up to 100% on the tangent. This will usually occur only in urban or suburban areas with highly restricted right-of-way conditions. The ratio should be rounded up or down as needed to simplify design and layout in construction.

2. Typical Figure. Figure 29-3E presents one method for superelevation development on a two-lane highway. Other methods may also be acceptable.

## 29-3.03 Axis of Rotation

### 29-3.03(a) Two-Lane Roadways

The axis of rotation will typically be about the centerline of the roadway on two-lane, two-way roadways. This method will yield the least amount of elevation differential between the pavement edges and their normal profiles. Occasionally, it may be necessary to rotate about the inside or outside edge of the traveled way. This may be necessary to meet field conditions (e.g., drainage, roadside development).

### 29-3.03(b) Multilane Roadways

For axis of rotation on a multilane roadway, see Section 32-3 of the *BDE Manual*.

## 29-3.04 Shoulder Superelevation

Figure 29-3F illustrates the shoulder treatment on superelevated sections. The following discusses specific criteria.

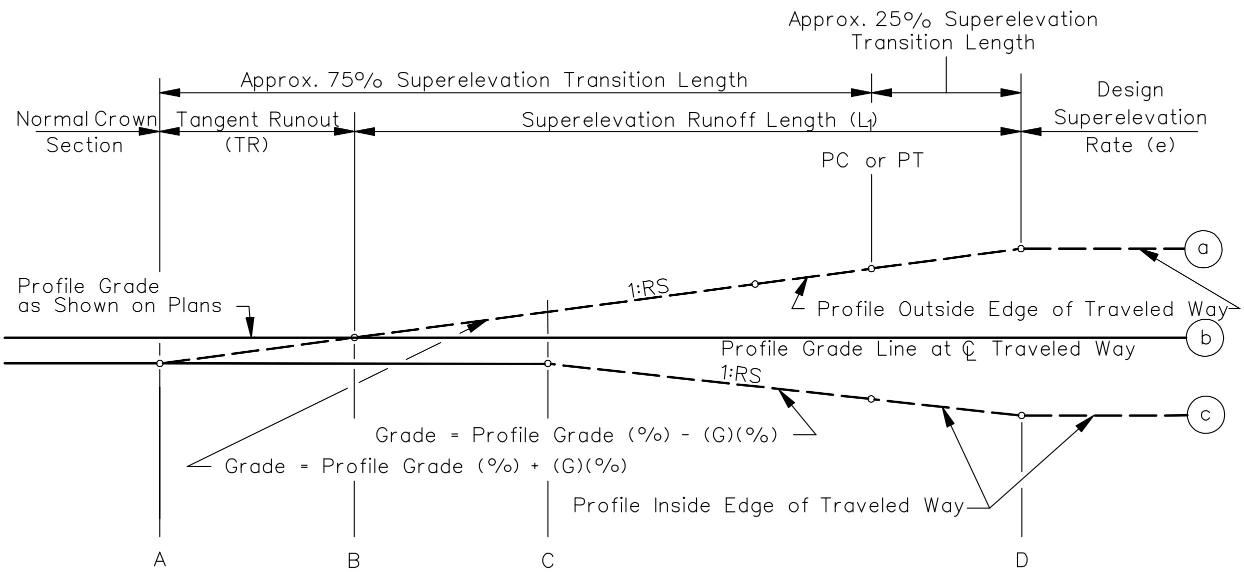
### 29-3.04(a) Shoulder (High Side of Curve)

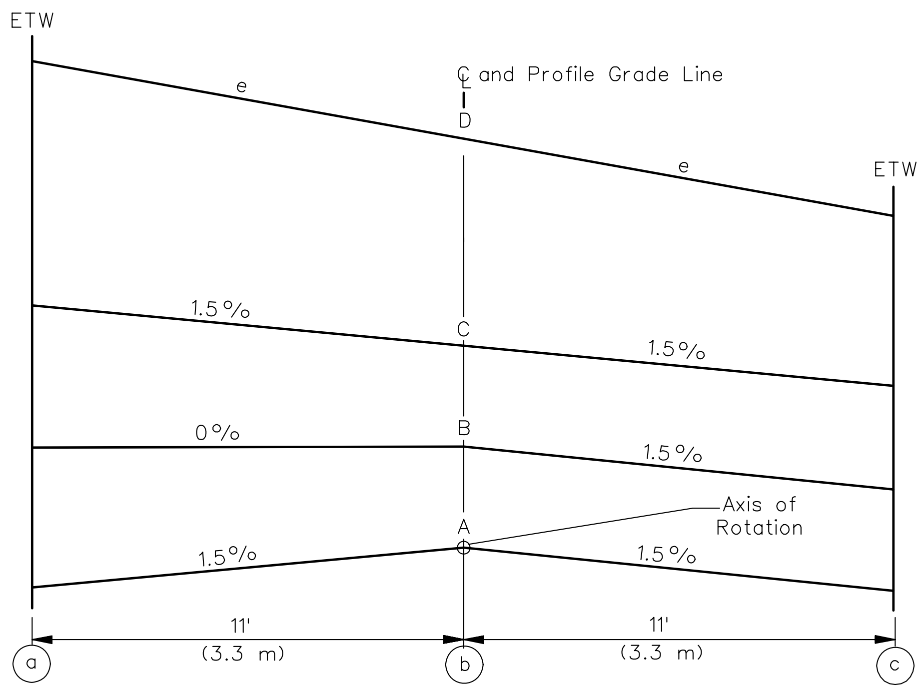
On the high side of superelevated sections, there will be a break in the cross slopes of the travel lane and shoulder. The following criteria will apply to the shoulder rollover:

1. Rollover Factor. The rollover factor is the algebraic difference between the traveled way and the shoulder cross slopes. The acceptable values depend on the design traffic volumes. See the Geometric Design Tables in Section 32-2 for new/reconstruction projects and Section 33-3 for 3R projects.

2. Minimum Shoulder Slope. On the high side of a curve, the shoulder slope may be designed for 0% so that maximum rollover is not exceeded. However, in this case, the longitudinal gradient at the edge of the traveled way should not be less than 0.5% for proper shoulder drainage.

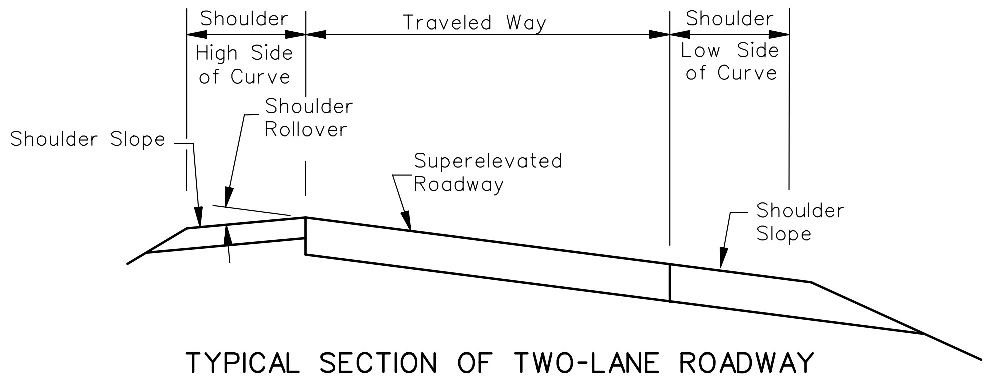
3. Direction of Slope. The shoulder should slope away from the travel lane.




**AXIS OF ROTATION ABOUT CENTERLINE**
**(Two-Lane Highway)**

**Figure 29-3E**




**SHOULDER TREATMENT THROUGH SUPERELEVATED CURVE**

**Figure 29-3F**

### 29-3.04(b) Shoulder (Low Side of Curve)

On the low side of a superelevated section, the typical practice is to retain the normal shoulder slope (4% typical) until the adjacent superelevated travel lane reaches that slope. The shoulder is then superelevated concurrently with the travel lane until the design superelevation rate is reached (i.e., the inside shoulder and travel lane will remain in the same plane section).

## 29-3.05 Reverse Curves

Because reverse curves are two closely spaced simple curves with deflections in opposite directions, it may not be practical to achieve a normal crown section between the curves. A plane section continuously rotating about its axis (e.g., the centerline) can be maintained between the two curves, if they are close enough together. The designer should adhere to the applicable superelevation development criteria for each curve. The following will apply to reverse curves:

1. Normal Crown Section. The designer should not attempt to achieve a normal crown between reverse curves unless the normal crown can be maintained for a minimum of two seconds of travel time, and the superelevation transition requirements can be met

for both curves. These criteria yield the following minimum tangent distance (between PT of first curve and PC of second curve):

$$L_{tan} = 0.75(L_{1A} + TR_A) + 2(1.467V) + 0.75(L_{1B} + TR_B)$$ (US Customary) Equation 29-3.3

$$L_{tan} = 0.75(L_{1A} + TR_A) + 2(0.278V) + 0.75(L_{1B} + TR_B)$$ (Metric) Equation 29-3.3

where:

$L_{tan}$ = tangent distance between PT and PC, ft (m)
$L_{1A}$ = superelevation runoff length for first curve, ft (m)
$TR_A$ = tangent runout length for first curve, ft (m)
$V$ = design speed, mph (km/h)
$L_{1B}$ = superelevation runoff length for second curve, ft (m)
$TR_B$ = tangent runout length for second curve, ft (m)

2. Continuously Rotating Plane. If a normal section is not provided, the pavement will be continuously rotated in a plane about its axis. In this case, the minimum distance between the PT and PC will be 75% of each superelevation transition requirement added together:

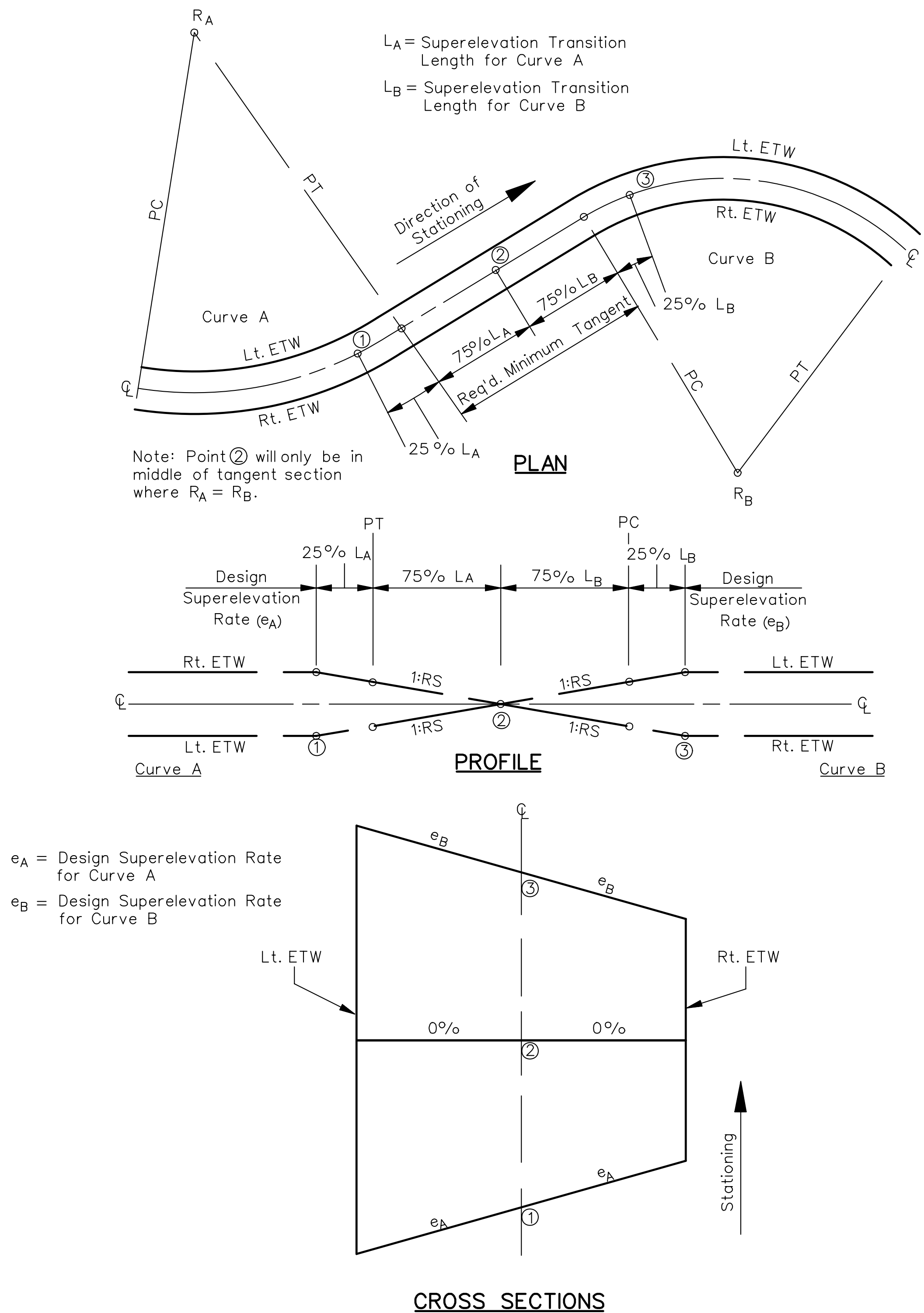
$$L_{tan} = 0.75(L_{1A} + TR_A) + 0.75(L_{1B} + TR_B)$$ Equation 29-3.4

Figure 29-3G illustrates superelevation development for reverse curves using a continuously rotating plane.

## 29-3.06 Bridges

Superelevation transitions should be avoided on bridges and their approaches. Where a curve is necessary on a bridge, the desirable treatment is to place the entire bridge and its approaches on a flat horizontal curve with minimum superelevation. In this case, a uniform superelevation rate is provided throughout (i.e., the superelevation transition is not on the bridge). In some cases, however, superelevation transitions are unavoidable due to right-of-way constraints, especially on urban bridges.

Where a bridge is located within a superelevated horizontal curve, the entire bridge roadway will be sloped in the same direction and at the same rate (i.e., the shoulder and travel lanes will be in a plane section). This also applies to the approach slab and approach slab shoulders before and after the back of the abutment. However, as discussed in Section 29-3.04, the high-side shoulder on a roadway section will slope away from the traveled way at a rate so that the maximum rollover is not exceeded.




**SUPERELEVATION DEVELOPMENT FOR REVERSE CURVES**
**(Continuously Rotating Plane)**

**Figure 29-3G**

Therefore, it is necessary to transition the longitudinal shoulder slope adjacent to the roadway travel lanes to meet the shoulder slope adjacent to the travel lanes on the bridge. This transition should be accomplished by using a maximum relative longitudinal gradient of 0.40% between the edge of traveled way and outside edge of shoulder.

## 29-3.07 Compound Curves

See Section 32-3 of the *BDE Manual* for a discussion on superelevation development for compound curves on mainline.

# 29-4 HORIZONTAL ALIGNMENT (Low-Speed Urban Streets)

## 29-4.01 General Application

For low-speed urban and suburban streets, the application of horizontal alignment criteria will differ from that for open-roadway conditions. Section 29-4 discusses the application to these facilities where $V \leq 45$ mph (70 km/h).

## 29-4.02 General Superelevation Considerations

For low-speed urban streets, the operational conditions and physical constraints are significantly different than those on rural roadways and high-speed urban roadways. The following lists some of the characteristics of low-speed urban streets that often complicate superelevation development:

1. Roadside Development/Intersections/Driveways. Built-up roadside development is common adjacent to low-speed urban streets. Matching superelevated curves with many driveways, intersections, sidewalks, etc., creates considerable complications. For example, this may require reconstructing the profile on side streets, and re-grading parking lots, lawns, etc., to compensate for the higher elevation on the high side of the superelevated curve.

2. Non-Uniform Travel Speeds. On low-speed urban streets, travel speeds are often non-uniform because of frequent signalization, stop signs, vehicular conflicts, etc. It is undesirable for traffic to stop on a superelevated curve, especially when snow or ice is present.

3. Limited Right-of-Way. Superelevated curves often result in more right-of-way impacts than would otherwise be necessary. Right-of-way is often restricted along low-speed urban streets.

4. Wide Pavement Areas. Many low-speed urban streets have wide pavement areas because of the number of traffic lanes, the use of a flush-type median, or the presence of parking lanes. In general, the wider the pavement area, the more complicated is the development of superelevation.

5. Surface Drainage. Proper cross slope drainage on low-speed urban streets can be difficult even on sections with a normal crown. Curves with superelevation introduce another complicating factor in controlling drainage.

## 29-4.03 Horizontal Curves

### 29-4.03(a) Design Procedures

Because of the different operational conditions for low-speed urban streets, it is appropriate to use a modified theoretical basis for horizontal alignment criteria when compared to open-roadway conditions. The net effect is:

- sharper minimum radii,
- fewer superelevated curves, and
- shorter superelevation runoff distances.

The practical benefit is that most horizontal curves can be designed with little or no superelevation on low-speed urban streets when compared to the criteria for open-roadway conditions in Section 29-3.

### 29-4.03(b) Maximum Superelevation Rate

For new construction projects, $e_{max}$ is 4.0% for low-speed urban streets. For urban reconstruction projects, existing horizontal curves can remain in place with a superelevation rate up to 6.0%.

### 29-4.03(c) Minimum Radii

Figure 29-4A presents for various design speeds for low-speed urban streets the:

- minimum radii for a normal crown section,
- minimum radii for $e_{max}$ = 4.0%, and
- minimum radii for $e_{max}$ = 6.0%.

Note that an $e_{max}$ = 6.0% may only be used to retain an existing superelevated curve on a reconstruction project.

### 29-4.03(d) Superelevation Rate

For any given design speed, Figure 29-4B allows the designer to use either a normal crown through the curve, to remove crown through the curve (i.e., superelevate at the typical cross slope), or to provide a curve with superelevation steeper than the typical cross slope.

| US Customary | | | | | |
|---|---|---|---|---|---|
| Design Speed (mph) | Side Friction Factor (f) | $R_{min}$ (ft) for Normal Crown (e = -1.5%) | $R_{min}$ (ft) for Remove Crown (e = +1.5%) | $R_{min}$ (ft) for $e_{max}$ = 4.0% | $R_{min}$ (ft) for $e_{max}$ = 6.0% |
| 20 | 0.300 | 95 | 85 | 80 | 75 |
| 25 | 0.252 | 180 | 160 | 145 | 135 |
| 30 | 0.221 | 295 | 255 | 230 | 215 |
| 35 | 0.197 | 450 | 385 | 345 | 320 |
| 40 | 0.178 | 655 | 555 | 490 | 450 |
| 45 | 0.163 | 915 | 760 | 665 | 610 |
| **Metric** | | | | | |
| Design Speed (km/h) | Side Friction Factor (f) | $R_{min}$ (m) for Normal Crown (e = -1.5%) | $R_{min}$ (m) for Remove Crown (e = +1.5%) | $R_{min}$ (m) for $e_{max}$ = 4.0% | $R_{min}$ (m) for $e_{max}$ = 6.0% |
| 30 | 0.312 | 24 | 22 | 21 | 20 |
| 40 | 0.252 | 54 | 48 | 44 | 41 |
| 50 | 0.214 | 99 | 86 | 78 | 72 |
| 60 | 0.186 | 166 | 142 | 126 | 116 |
| 70 | 0.163 | 261 | 217 | 191 | 174 |

**MINIMUM RADII FOR LIMITING VALUES OF e**
**(Low-Speed Urban Streets)**

**Figure 29-4A**

* * * * * * * * * *

**Example 29-4.1**

Given: Design speed = 25 mph
Radius = 200 ft
Cross slope (on tangent) = 1.5%

Problem: Determine if superelevation is needed.

Solution: From Figure 29-4B, the normal crown section can be maintained throughout the horizontal curve.

* * * * * * * * * *

| e | V = 20 mph | | | V = 25 mph | | | V = 30 mph | | |
|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 95 | 0 | 0 | R ≥ 180 | 0 | 0 | R ≥ 295 | 0 | 0 |
| RC | 95 > R ≥ 85 | 21 | 21 | 180 > R ≥ 160 | 22 | 22 | 295 > R ≥ 255 | 25 | 25 |
| 2.0% | 85 > R ≥ 84 | 27 | 21 | 160 > R ≥ 154 | 30 | 22 | 255 > R ≥ 249 | 33 | 25 |
| 2.5% | 84 > R ≥ 83 | 34 | 21 | 154 > R ≥ 151 | 37 | 22 | 249 > R ≥ 244 | 41 | 25 |
| 3.0% | 83 > R ≥ 81 | 41 | 21 | 151 > R ≥ 148 | 44 | 22 | 244 > R ≥ 239 | 49 | 25 |
| 3.5% | 81 > R ≥ 80 | 47 | 21 | 148 > R ≥ 146 | 51 | 22 | 239 > R ≥ 235 | 57 | 25 |
| 4.0% | 80 > R ≥ 80 | 54 | 21 | 146 > R ≥ 145 | 59 | 22 | 235 > R ≥ 230 | 65 | 25 |
| 4.5% | 80 > R ≥ 78 | 61 | 21 | 145 > R ≥ 141 | 66 | 22 | 230 > R ≥ 226 | 73 | 25 |
| 5.0% | 78 > R ≥ 77 | 67 | 21 | 141 > R ≥ 138 | 73 | 22 | 226 > R ≥ 222 | 81 | 25 |
| 5.5% | 77 > R ≥ 76 | 74 | 21 | 138 > R ≥ 136 | 81 | 22 | 222 > R ≥ 218 | 89 | 25 |
| 6.0% | 76 > R ≥ 75 | 81 | 21 | 136 > R ≥ 135 | 88 | 22 | 218 > R ≥ 215 | 97 | 25 |

| e | V = 35 mph | | | V = 40 mph | | | V = 45 mph | | |
|---|---|---|---|---|---|---|---|---|---|
| | R (ft) | Trans. Length | | R (ft) | Trans. Length | | R (ft) | Trans. Length | |
| | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) | | $L_1$ (ft) | TR (ft) |
| NC | R ≥ 450 | 0 | 0 | R ≥ 655 | 0 | 0 | R ≥ 915 | 0 | 0 |
| RC | 450 > R ≥ 385 | 26 | 26 | 655 > R ≥ 555 | 28 | 28 | 915 > R ≥ 760 | 30 | 30 |
| 2.0% | 385 > R ≥ 377 | 35 | 26 | 555 > R ≥ 539 | 37 | 28 | 760 > R ≥ 738 | 39 | 30 |
| 2.5% | 377 > R ≥ 368 | 43 | 26 | 539 > R ≥ 526 | 46 | 28 | 738 > R ≥ 719 | 49 | 30 |
| 3.0% | 368 > R ≥ 360 | 52 | 26 | 526 > R ≥ 513 | 55 | 28 | 719 > R ≥ 700 | 59 | 30 |
| 3.5% | 360 > R ≥ 352 | 61 | 26 | 513 > R ≥ 501 | 64 | 28 | 700 > R ≥ 682 | 69 | 30 |
| 4.0% | 352 > R ≥ 345 | 69 | 26 | 501 > R ≥ 490 | 73 | 28 | 682 > R ≥ 665 | 78 | 30 |
| 4.5% | 345 > R ≥ 338 | 78 | 26 | 490 > R ≥ 479 | 82 | 28 | 665 > R ≥ 649 | 88 | 30 |
| 5.0% | 338 > R ≥ 331 | 86 | 26 | 479 > R ≥ 468 | 91 | 28 | 649 > R ≥ 634 | 98 | 30 |
| 5.5% | 331 > R ≥ 325 | 95 | 26 | 468 > R ≥ 458 | 100 | 28 | 634 > R ≥ 620 | 108 | 30 |
| 6.0% | 325 > R ≥ 320 | 103 | 26 | 458 > R ≥ 450 | 109 | 28 | 620 > R ≥ 610 | 118 | 30 |

Key:

R = Radius of curve, ft
V = Design speed, mph
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), ft
TR = Tangent runout from NC to adverse slope removed, ft
NC = Normal crown = 1.5% typical
RC = Remove adverse crown; superelevate at typical cross slope (1.5% typical)

*Notes:*

1. *For new construction projects,* $e_{max}$ *= 4.0%.*
2. *For reconstruction projects,* $e_{max}$ *= 6.0%.*

**SUPERELEVATION RATES**
**(Low-Speed Urban Streets) (US Customary)**

**Figure 29-4B**

| e | V = 30 km/h | | | V = 40 km/h | | | V = 50 km/h | | |
|---|---|---|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 24 | 0 | 0 | R ≥ 54 | 0 | 70 | R ≥ 99 | 0 | 0 |
| RC | 24 > R ≥ 22 | 7 | 7 | 54 > R ≥ 48 | 7 | 7 | 99 > R ≥ 86 | 8 | 8 |
| 2.0% | R = 22 | 9 | 7 | 48 > R ≥ 47 | 9 | 7 | 86 > R ≥ 85 | 10 | 8 |
| 2.5% | 22 > R ≥ 21 | 11 | 7 | 47 > R ≥ 46 | 12 | 7 | 85 > R ≥ 83 | 13 | 8 |
| 3.0% | R = 21 | 13 | 7 | 46 > R ≥ 45 | 14 | 7 | 83 > R ≥ 81 | 15 | 8 |
| 3.5% | R = 21 | 15 | 7 | 45 > R ≥ 44 | 16 | 7 | 81 > R ≥ 80 | 18 | 8 |
| 4.0% | R = 21 | 17 | 7 | 44 > R ≥ 44 | 18 | 7 | 80 > R ≥ 78 | 20 | 8 |
| 4.5% | 21 > R ≥ 20 | 19 | 7 | 44 > R ≥ 43 | 21 | 7 | 78 > R ≥ 76 | 23 | 8 |
| 5.0% | R = 20 | 21 | 7 | 43 > R ≥ 42 | 23 | 7 | 76 > R ≥ 75 | 25 | 8 |
| 5.5% | R = 20 | 23 | 7 | 42 > R ≥ 41 | 25 | 7 | 75 > R ≥ 74 | 28 | 8 |
| 6.0% | R = 20 | 25 | 7 | R = 41 | 27 | 7 | 74 > R ≥ 72 | 30 | 8 |

| e | V = 60 km/h | | | V = 70 km/h | | |
|---|---|---|---|---|---|---|
| | R (m) | Trans. Length | | R (m) | Trans. Length | |
| | | $L_1$ (m) | TR (m) | | $L_1$ (m) | TR (m) |
| NC | R ≥ 166 | 0 | 0 | R ≥ 261 | 0 | 0 |
| RC | 166 > R ≥ 142 | 9 | 9 | 261 > R ≥ 217 | 9 | 9 |
| 2.0% | 142 > R ≥ 138 | 11 | 9 | 217 > R ≥ 211 | 12 | 9 |
| 2.5% | 138 > R ≥ 135 | 14 | 9 | 211 > R ≥ 206 | 15 | 9 |
| 3.0% | 135 > R ≥ 132 | 17 | 9 | 206 > R ≥ 200 | 18 | 9 |
| 3.5% | 132 > R ≥ 129 | 19 | 9 | 200 > R ≥ 195 | 21 | 9 |
| 4.0% | 129 > R ≥ 126 | 22 | 9 | 195 > R ≥ 191 | 24 | 9 |
| 4.5% | 126 > R ≥ 123 | 25 | 9 | 191 > R ≥ 186 | 27 | 9 |
| 5.0% | 123 > R ≥ 121 | 28 | 9 | 186 > R ≥ 182 | 30 | 9 |
| 5.5% | 121 > R ≥ 118 | 30 | 9 | 182 > R ≥ 177 | 33 | 9 |
| 6.0% | 118 > R ≥ 116 | 33 | 9 | 177 > R ≥ 174 | 36 | 9 |

Key:

R = Radius of curve, m
V = Design speed, km/h
e = Superelevation rate, %
$L_1$ = Minimum length of superelevation runoff (from adverse slope removed to full super), m
TR = Tangent runout from NC to adverse slope removed, m

*Notes:*

1. *For new construction projects, $e_{max}$ = 4.0%.*
2. *For reconstruction projects, $e_{max}$ = 6.0%.*

**SUPERELEVATION RATES**
**(Low-Speed Urban Streets) (Metric)**

**Figure 29-4B**

* * * * * * * * * *

**Example 29-4.2**

Given: Design speed = 35 mph
Radius = 400 ft
Cross slope (on tangent) = 1.5%

Problem: Determine if superelevation is needed.

Solution: From Figure 29-4B, the curve radius falls in the RC range. Therefore, the roadway must be uniformally superelevated at the cross slope of the roadway on tangent (i.e., e = +1.5%).

**Example 29-4.3**

Given: Design speed = 40 mph
Radius = 500 ft
Cross slope (on tangent) = 1.5%

Problem: Determine if superelevation is needed.

Solution: From Figure 29-4B, the required superelevation rate is +4.0%. Therefore, the entire traveled way should be transitioned and superelevated at this rate.

* * * * * * * *

## 29-4.04 Superelevation Development

### 29-4.04(a) Transition Length

The superelevation transition length is the distance required to transition the traveled way from a normal crown section to the full design superelevated section. The superelevation transition length is the sum of the tangent runout distance (TR) and superelevation runoff length ($L_1$). See Section 29-3.

Section 29-3 presents the methodology for calculating the superelevation runoff and tangent runout for open-roadway conditions. This methodology also applies to superelevation transition lengths on low-speed urban streets, except that Figure 29-4C presents revised relative longitudinal gradients.

Based on values from Figure 29-4C, Figure 29-4B presents superelevation runoff lengths ($L_1$) for a two-lane urban street, assuming the axis of rotation is about the roadway centerline; i.e., the width of rotation is one travel lane of 13 ft (4.0 m). See Section 29-3 for determining the tangent runout distance. See Section 32-3 of the *BDE Manual* for determining superelevation transition lengths on multilane facilities.

| US Customary | | | Metric | | |
|---|---|---|---|---|---|
| Design Speed (mph) | Maximum Relative Gradient (%) | Reciprocal (RS) | Design Speed (km/h) | Maximum Relative Gradient (%) | Reciprocal (RS) |
| 20 | 0.97 | 103 | 30 | 0.98 | 102 |
| 25 | 0.90 | 112 | 40 | 0.90 | 112 |
| 30 | 0.81 | 124 | 50 | 0.80 | 125 |
| 35 | 0.76 | 132 | 60 | 0.74 | 136 |
| 40 | 0.72 | 139 | 70 | 0.68 | 148 |
| 45 | 0.67 | 150 | | | |

**RELATIVE LONGITUDINAL GRADIENTS**
**(Low-Speed Urban Streets)**

**Figure 29-4C**

Typically, 75% of the superelevation transition length will be placed on tangent and 25% on curve. Exceptions to this practice may be necessary to meet field conditions. Generally, the accepted range is 50% to 80% on tangent and 20% to 50% on curve.

### 29-4.04(b) Axis of Rotation

On low-speed urban streets, the axis of rotation for horizontal curves is as follows:

1. Two-Lane Facilities. The axis of rotation is typically about the centerline of the roadway.

2. Multilane Facilities (Median Width ≤ 15 ft (5.0 m)). The axis of rotation is typically about the centerline of roadway or median.

3. Multilane Facilities (Median Width > 15 ft (5.0 m)). The axis of rotation is typically about the two median edges.

Low-speed urban streets may also present special problems because of the presence of two-way, left-turn lanes; turning lanes at intersections; intersections with major crossroads; drainage; etc. For these reasons, the axis of rotation may be determined on a case-by-case basis.

## 29-5 HORIZONTAL SIGHT DISTANCE

Horizontal curves must be designed with sufficient clearance on the inside of the curve to allow a driver to see a distance equal to the stopping sight distance for the design speed; see Chapter 28.

### 29-5.01 Sight Obstruction (Definition)

Sight obstructions on the inside of a horizontal curve are defined as obstacles of considerable length that interfere with the line of sight on a continuous basis. These include walls, cut slopes, wooded areas, and buildings. In general, point obstacles (e.g., traffic signs, utility poles) are not considered sight obstructions on the inside of horizontal curves. While high farm crops are not present on a continuous basis, the designer may also want to take this into consideration when designing for sight distance. The designer must examine each curve individually to determine whether it is necessary to remove an obstruction or adjust the horizontal alignment to obtain the required sight distance.

### 29-5.02 Application

For sight distance applications at horizontal curves, the height of eye is 3.5 ft (1080 mm) and the height of object is 2 ft (600 mm). Both the eye and object are assumed to be in the center of the inside travel lane. The line-of-sight intercept with the obstruction is at the midpoint of the sightline and 2.75 ft (840 mm) above the center of the inside lane.

### 29-5.03 Curve Length > Sight Distance

Where the length of curve (L) is greater than the sight distance (S) used for design, the needed clearance on the inside of the horizontal curve is calculated using the following equation:

$$M = R\left(1 - \cos\frac{(28.65S)}{R}\right) \qquad \text{Equation 29-5.1}$$

where:

M = middle ordinate, or distance from the center of the inside travel lane to the obstruction, ft (m)

R = radius of curve, ft (m)

S = sight distance, ft (m)

At a minimum, SSD will be available throughout the horizontal curve. Figure 29-5A provides the horizontal clearance criteria (i.e., middle ordinate) for various combinations of sight distance (see Figure 28-1A) and curve radii. For those selections of S, that fall outside of the figures (i.e., M > 40 ft (12 m) and/or R < 100 ft (50 m)), the designer should use Equation 29-5.1 to calculate the needed clearance.

The M values from Figure 29-5A apply between the PC and PT. In addition, some transition is needed on the entering and exiting portions of the curve. The designer should typically use the following steps:

Step 1: Locate the point that is on the outside edge of shoulder and a distance of S/2 before the PC.

Step 2: Locate the point that is a distance M measured laterally from the center of the inside travel lane at the PC.

Step 3: Connect the two points located in Steps 1 and 2. The area between this line and the roadway should be clear of all continuous obstructions.

Step 4: A symmetrical application of Steps 1 through 3 should be used beyond the PT.

The example in Figure 29-5B illustrates the determination of clearance requirements for the entering and exiting portions of a curve.

## 29-5.04 Curve Length < Sight Distance

When the length of curve is less than the sight distance used in design, the M value from the basic equation will never be reached. As an approximation, the horizontal clearance for these curves should be determined as follows:

Step 1: For the given R and S, calculate M assuming L > S.

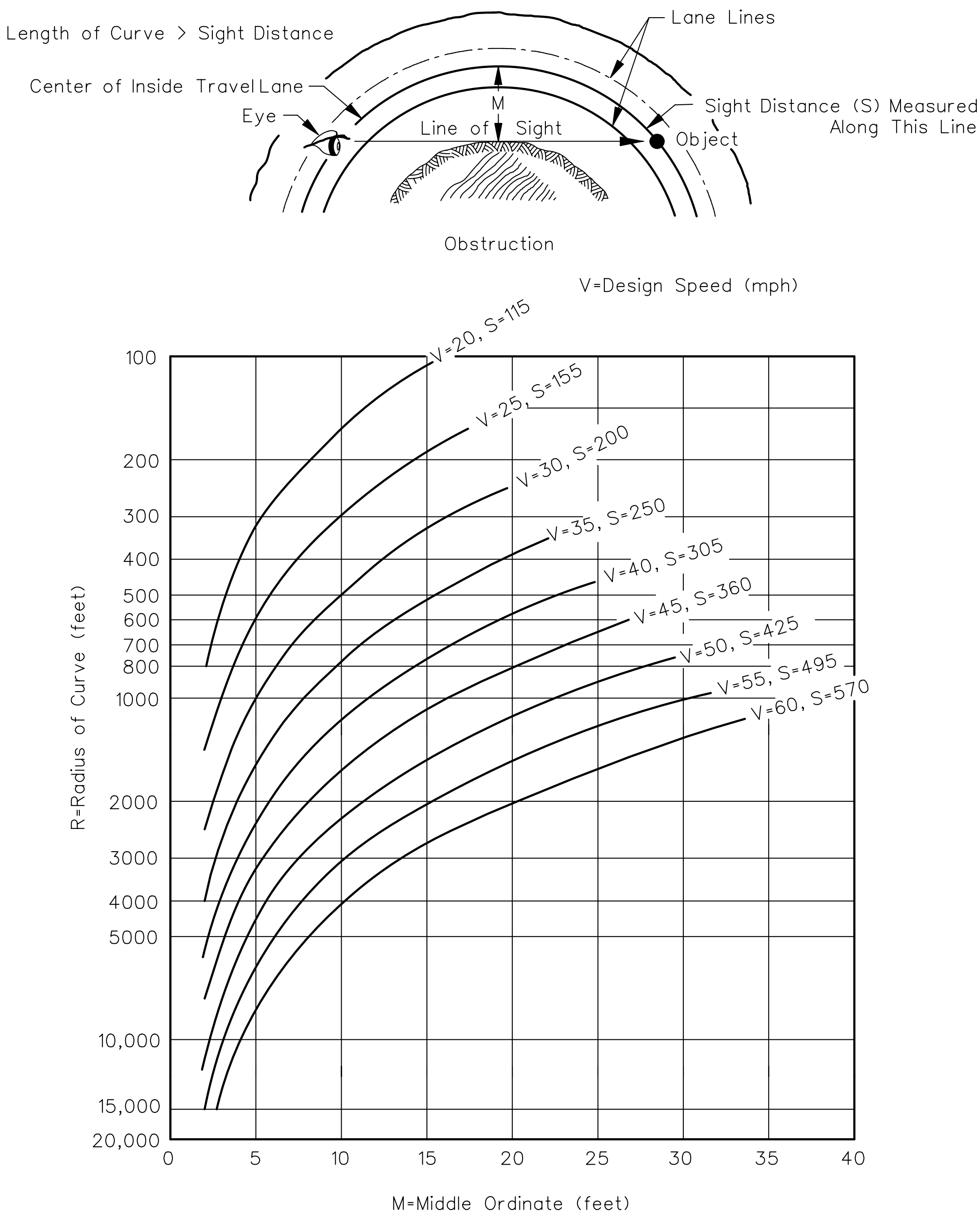
Step 2: The maximum M′ value will be needed at a point of L/2 beyond the PC. M′ is calculated from the following proportion:

$$\frac{M'}{M} = \frac{1.2L}{S} \qquad \text{Equation 29-5.2}$$

$$M' = \frac{1.2(L)(M)}{S}$$

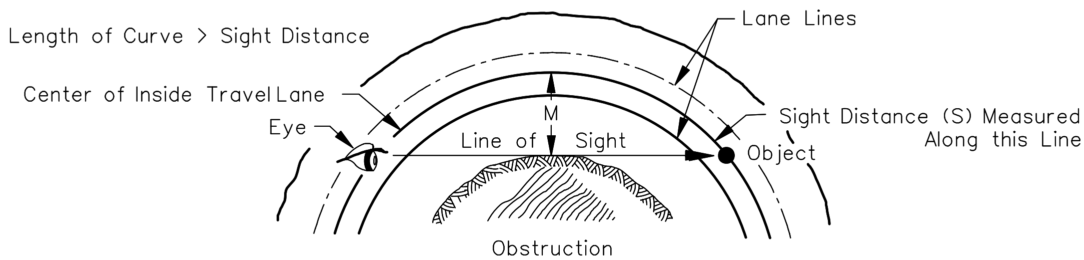
where:

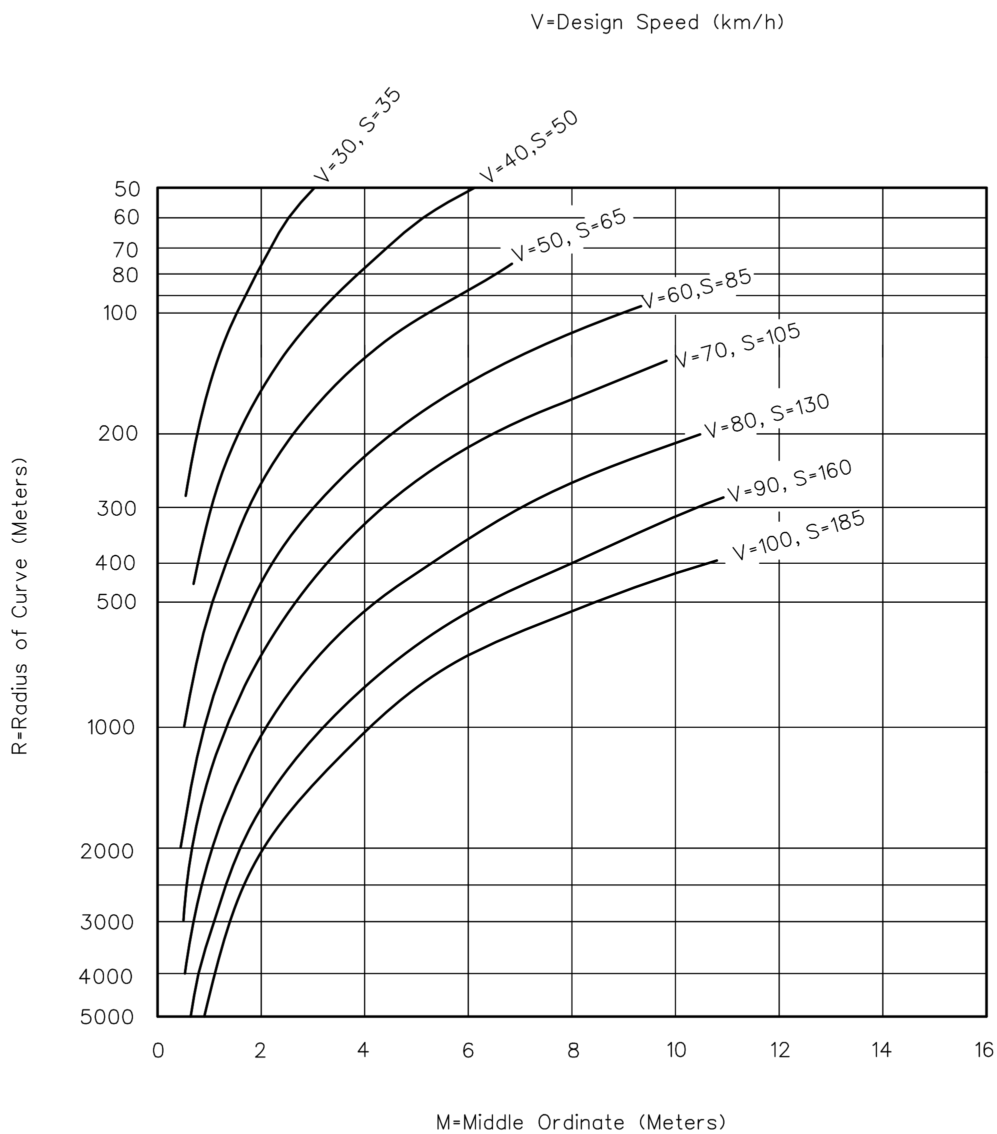
M′ = middle ordinate for a curve where L < S, ft (m)
M = middle ordinate for the curve based on Equation 29-5.1, ft (m)
L = length of the curve, ft (m)
S = sight distance, ft (m)




**SIGHT DISTANCE AT HORIZONTAL CURVES (SSD) (US Customary)**

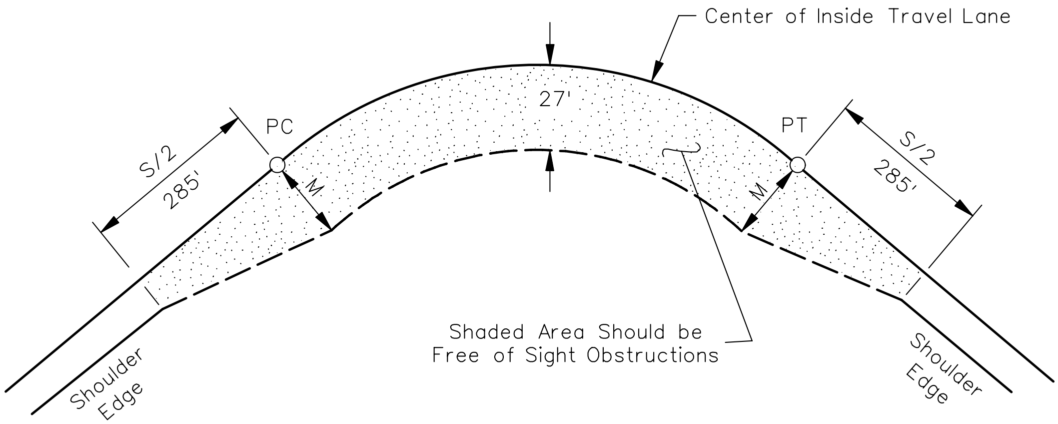
**Figure 29-5A**




**SIGHT DISTANCE AT HORIZONTAL CURVES (SSD) (Metric)**

**Figure 29-5B**




**Example 29-5.1**

Given: Design Speed = 60 mph
R = 1500 ft

Problem: Determine the horizontal clearance requirements for a horizontal curve on a 2-lane highway that meets the SSD requirements.

Solution: Figure 28-1A yields a SSD = 570 ft. Using Equation 29-5.1 for horizontal clearance (L > S):

$$M = R\left(1 - \cos\left[\frac{28.65\,S}{R}\right]\right)$$

$$M = 1500\left(1 - \cos\left[\frac{(28.65)(570)}{1500}\right]\right) = 27 \text{ ft}$$

This answer is verified by Figure 29-5A.

The above figure also illustrates the horizontal clearance requirements for the entering and exiting portion of the horizontal curve.

**SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES**
**(L > S)**

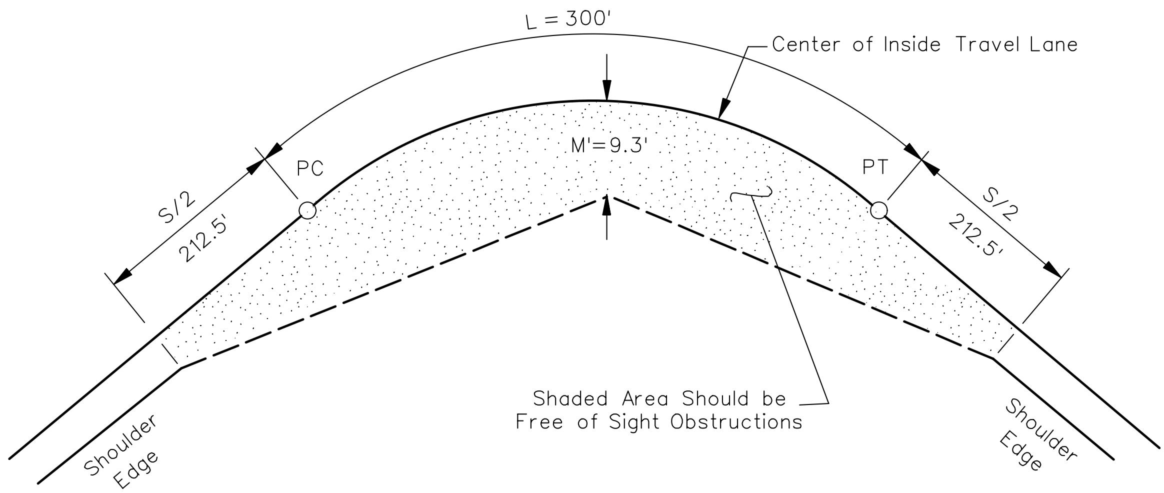
**Figure 29-5B**

Step 3: Locate the point that is on the outside edge of shoulder and a distance of S/2 before the PC.

Step 4: Connect the two points located in Steps 2 and 3. The area between this line and the roadway should be clear of all continuous obstructions.

Step 5: A symmetrical application of Steps 2 through 4 should be used on the exiting portion of curve.

The example on Figure 29-5C illustrates the determination of clearance requirements for the entering and exiting portions of a curve where $L < S$.




**Example 29-5.2**

Given: Design Speed = 50 mph
R = 2050 ft
L = 300 ft

Problem: Determine the clearance requirements for the horizontal curve on a 2-lane highway that meets the SSD requirements.

Solution: Figure 28-1A yields a SSD of 425 ft for 50 mph. Therefore, L < S (300 ft < 425 ft), and the horizontal clearance is calculated from Equation 29-5.2 as follows:

$$M\,(L > S) = 2050\left[1 - \cos\frac{(28.65)(425)}{2050}\right] = 11.01\,\text{ft}$$

$$M'\ (L < S) = \frac{1.2(300)(11.01)}{425}$$

$$M' = 9.3\ \text{ft}$$

Therefore, a minimum clearance of 9.3 ft should be provided at a distance of L/2 = 150 ft beyond the PC. The obstruction-free triangle around the horizontal curve would be defined by M′ (9.3 ft) at L/2 and by points at the shoulder edge at S/2 = 212.5 ft before the PC and beyond the PT.

**SIGHT CLEARANCE REQUIREMENTS FOR HORIZONTAL CURVES**
**(L < S)**

**Figure 29-5C**

## 29-6 REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004.

2. Chapter 32 "Horizontal Alignment" and Chapter 48 "Urban Highways and Streets (New Construction/Reconstruction)," *Bureau of Design and Environment Manual*, IDOT.